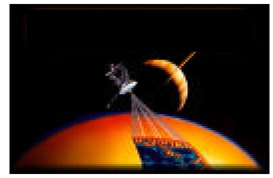

GAVRT Antenna, Deep Space Station 12


Deep Space Station 13


Jupiter


Cassini Spacecraft


Artist's Rendition of Radar Mission at Titan

PHOTOS: JPL/NASA

# Measuring the Radio Brightness of Jupiter

**Background Information for Teachers**

The Cassini-Jupiter Microwave Observing Campaign (JMOC) science mission will calibrate the Cassini Radar Receiver in-flight during Cassini's flyby of Jupiter in December 2000 and perform scientific investigations of Jupiter's radiation belts. The Goldstone Apple Valley Radio Telescope (GAVRT) project, part of the Lewis Center for Educational Research in Apple Valley, California has a unique opportunity to assist with the Cassini-JMOC science mission. Data collected by the participating GAVRT schools will be added to the database that is used to calibrate the radar receiver aboard the Cassini spacecraft. This calibration will assist the Cassini spacecraft's mission by allowing more precise measurements to be made by the spacecraft's radar system. This will be particularly useful when Cassini reaches Saturn's moon, Titan. One of the Cassini mission objectives is to penetrate the opaque atmosphere of Titan and map the satellite's surface. The radar mapping, along with other experiments, will help to determine the shape and composition of Titan's surface and give scientists clues about the internal structure of Titan. Greater precision of measurement, as a result of the calibration process, will provide a more reliable set of clues about Titan. Radar system measurements of other targets in the Saturn system, including the rings and other, icy satellites, will also benefit.

**Overview:**

Students will be analyzing brightness temperatures of Jupiter at three different frequencies and the radio calibration sources used in the observation process. Students will be introduced to the concept of radio calibration sources using an in-class simulation (Student Activity One). After the simulation exercise, students will analyze actual data from Jupiter observation sessions provided by participating GAVRT schools (Student Activity Two).

**Purposes:**

1. to better understand the processes and importance of calibration in scientific inquiry
2. to participate in the scientific process
3. to analyze data using a spreadsheet and graphing program

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**Students will be able to:**
Evaluate the radio brightness of Jupiter for three frequencies, collected using different calibration sources
Experience research science and gain a deeper understanding of the process nature of scientific investigation and discovery

**Resources/Materials needed:**

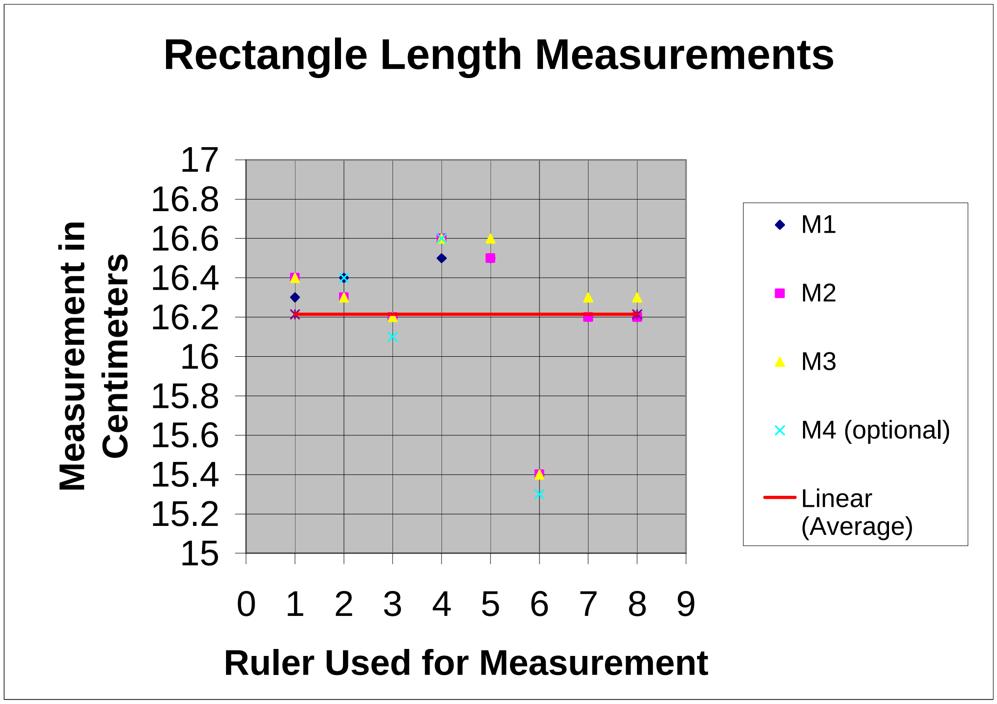
| | |
|---|---|
| Student pages | Download the data located for “ratio_measurement_graph_092.xls” |
| Scissors | Computer with Excel ® software, version 5.0 or higher |
| | Excel spreadsheet provided for data analyses |

*This lesson set is applicable to Mid-Continent Research for Education and Learning (McREL) Science Education standards as outlined in pages 11 - 14 of this document. Each standard is potentially applicable wholly or partially, depending on implementation strategies in individual classrooms.*

**Teacher Notes for Student Activity One:**
There is a resource page (page 5) with 8 rulers and a resource page with standard-sized objects (page 6) included with this activity. You will note that the dimensions vary from ruler to ruler. You will need to pre-cut a classroom set of rulers for this activity and a rectangle for each group. The students should not see this prior to doing the activity. (You may choose to provide one ruler per group or to provide all members of each group with the same # ruler.) This works better if the ruler page is printed on heavy weight paper such as cardstock.
Divide your students into eight groups of three or more. Each group of students should receive a numbered ruler (or set of same # rulers). If you have less than 24 students and need to make fewer than eight groups, it is best to omit ruler #1, then #8. Do not make groups of less than three students.
Have each group measure the length of the rectangle using the ruler(s) provided. Each student in each group should have an opportunity to make a measurement. The data will be recorded in a chart like the one that follows. If you choose to use an object other than the rectangle, please make sure that all objects are the same, such as calibrated masses, and that the objects are at least 11 cm in length but less than 15 cm. This will allow significant measurement differences to illustrate the point of this simulation.

| Ruler # | M1 | M2 | M3 | M4 (optional) |
|---|---|---|---|---|
| 1 | 16.3 | 16.4 | 16.4 | |
| 2 | 16.4 | 16.3 | 16.3 | 16.4 |
| 3 | 16.2 | 16.2 | 16.2 | 16.1 |
| 4 | 16.5 | 16.6 | 16.6 | 16.6 |
| 5 | 16.5 | 16.5 | 16.6 | |
| 6 | 15.4 | 15.4 | 15.4 | 15.3 |
| 7 | 16.2 | 16.2 | 16.3 | |
| 8 | 16.2 | 16.2 | 16.3 | |

These data will be used to produce a scatter plot like the one that follows.




The questions in Student Activity One lead the students to evaluate why the measurements differ from ruler to ruler. Students should question the ruler instrument and realize that each ruler may not be exactly the same. Students should also realize that the object being measured has not changed. If the rulers (analogous to the radio calibration sources in activity two) are not well-understood (in this case, not exact according to standard metric measure), they may not agree with one another. This will lead to a discussion of the use of radio calibration sources in Student Activity Two.

**Teacher Notes for Student Activity Two**

Radio calibration sources, unlike rulers, cannot be produced to certain specifications. Scientists must compare objects they are studying, like Jupiter, to objects that are already well understood. Radio astronomers use galaxies, quasars, supernovas, planets, and nebulae that emit at radio wavelengths as radio calibration sources. These radio calibration sources have been observed over time, over a wide range of frequencies, using multiple instruments *with consistent results*. The more consistent the results, the more confidence scientists can have in a source. As a result, there is a list of radio calibration sources with “known” brightness temperatures at various frequencies for each source. Scientists can use these to make comparisons against. Our study object is Jupiter for this experiment.

One of the unique aspects of this science mission is that the observations made using ground-based instruments such as DSS-12 and DSS-13 and the radar instrument on the Cassini spacecraft will promote better understanding of the calibration sources themselves.

**Step One:** The ground-based instruments use the data from observing well understood radio source calibrators at all four listed frequencies to compare with observations of a study object like Jupiter. Having measurements at four frequencies allows scientists to better understand how the brightness temperature of an object changes with frequency. Once those ground-based instruments are well calibrated when comparing radio source calibrators to data from Jupiter at the four frequencies, the spacecraft observes Jupiter also at 13.8 GHz.

**Step Two:** The ground-based calibrated measurements of Jupiter can then be compared to the spacecraft measurements of Jupiter. This comparison can be used to calibrate the radar instrument on the spacecraft.

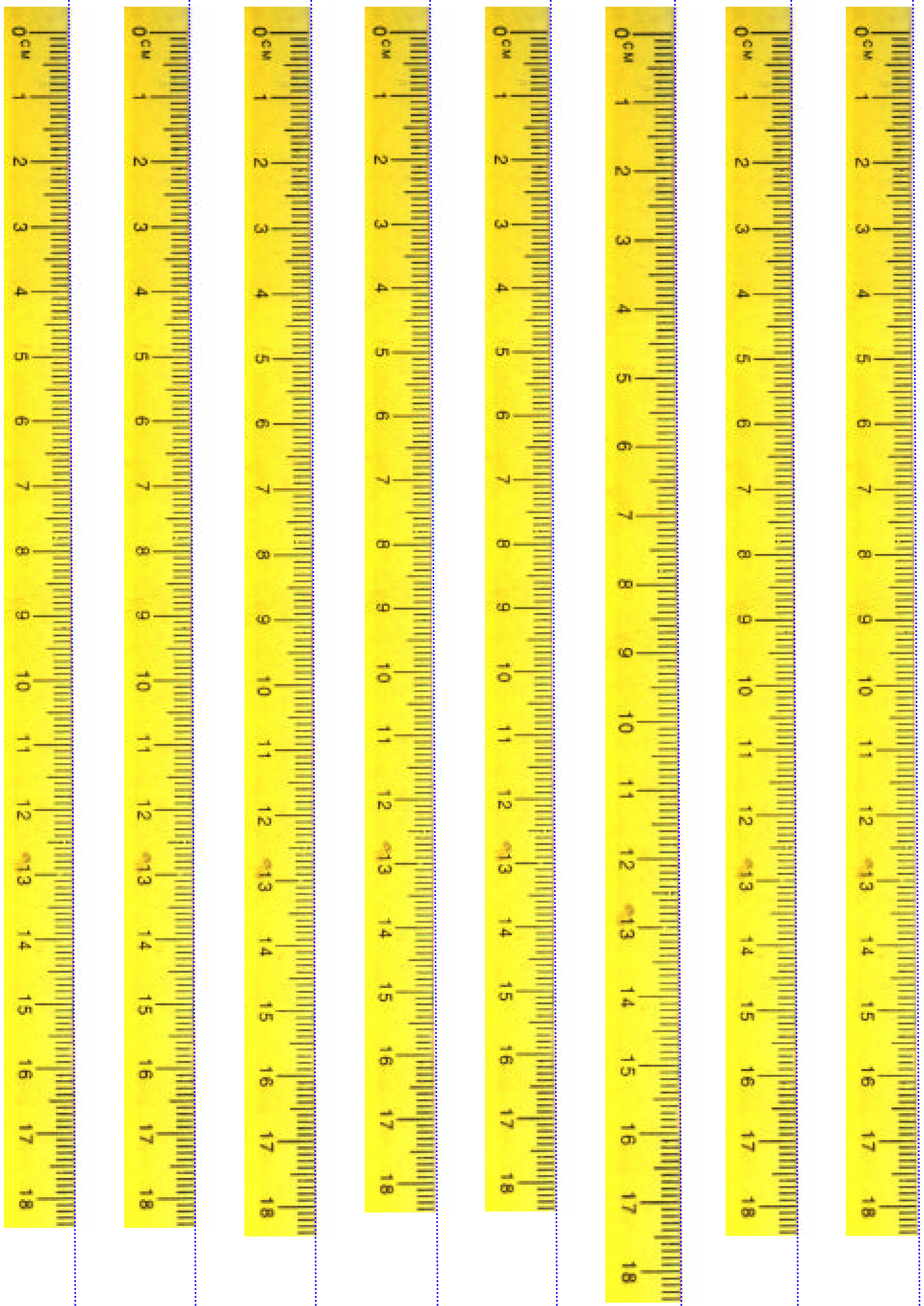
Through these measurements and comparisons, using multiple instruments at the four different frequencies, and multiple radio calibration sources, the radio calibration source themselves may be better understood, improving the precision of all the measurements.

Students will refer to “ratio_measurement_graph_092.xls” to view and print the data and graphs for Jupiter’s brightness temperature at each of the following frequencies: 8.480 MHz, 13. 8MHz, and 32 MHz. These data are from the ground-based observations. Students should look at each graph, first individually and then in comparison to one another. Discussion questions provided for Students Activity Two will guide this activity.

## Vocabulary

| | |
|---|---|
| Radio Brightness | This is another way of describing the synchrotron radiation intensity. This is how bright a source appears in the radio spectrum, and is measured in degrees Kelvin for this exercise (It can be expressed in other units of measurement.) |
| Radio Calibration Source | Radio calibration sources are objects such as galaxies, pulsars, quasars, and even planets that emit energy in the radio part of the spectrum at fairly well understood and consistent strengths over time. These sources are used for comparison to objects of study, such as Jupiter in this case. |

**1** **2** **3** **4** **5** **6** **7** **8**



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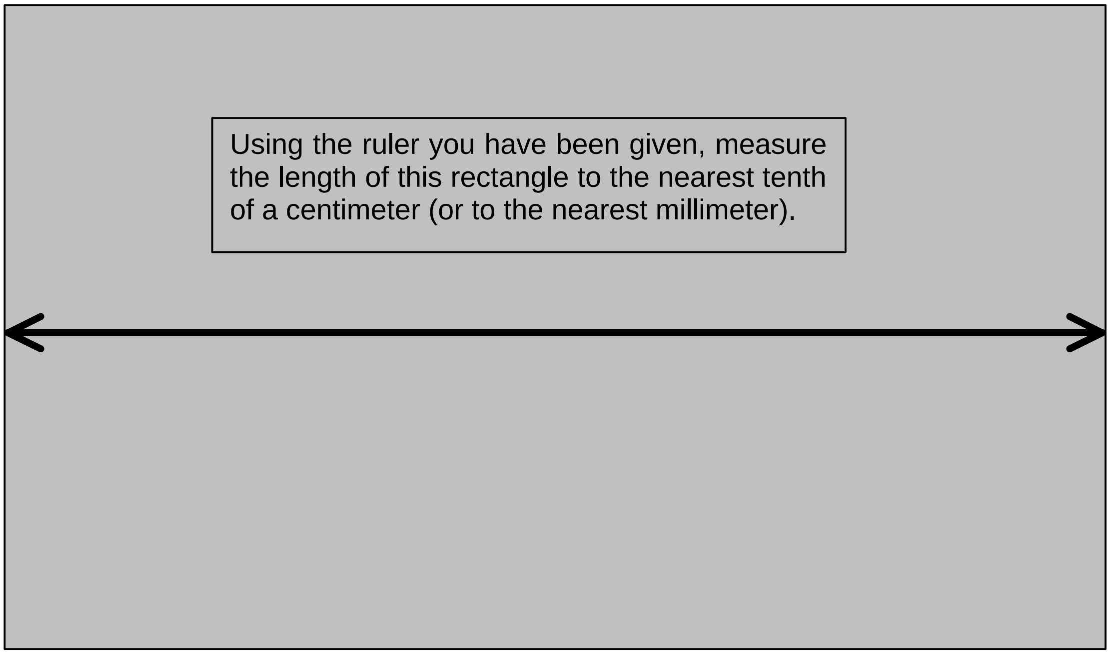
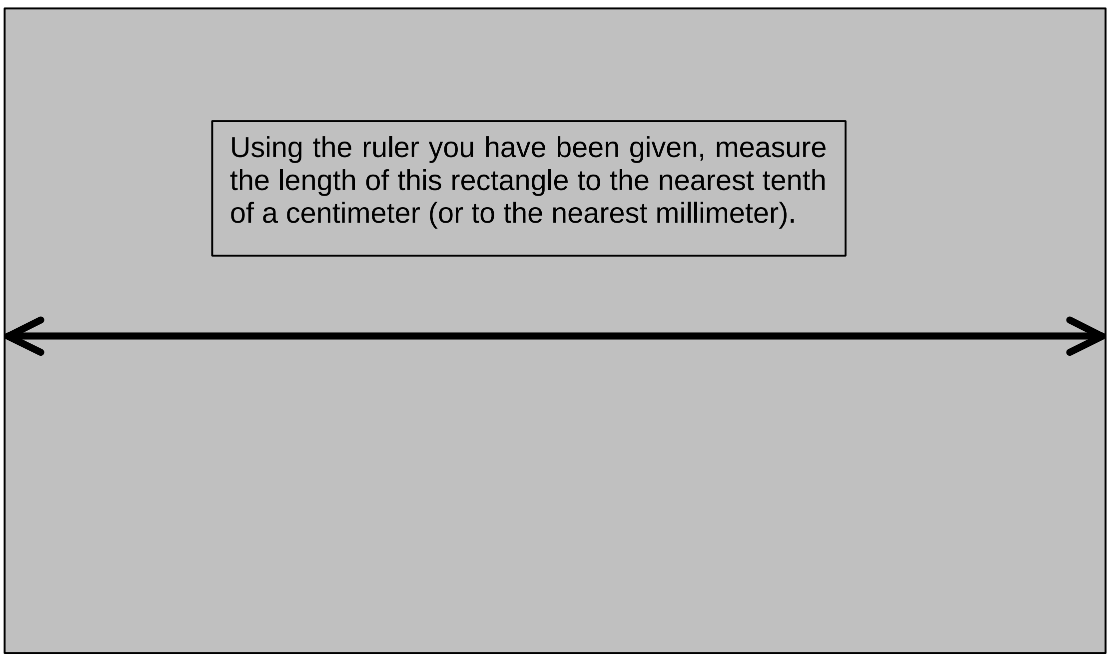

Using the ruler you have been given, measure the length of this rectangle to the nearest tenth of a centimeter (or to the nearest millimeter).


Using the ruler you have been given, measure the length of this rectangle to the nearest tenth of a centimeter (or to the nearest millimeter).

## Measuring the Brightness of Jupiter – Student Activity One

**Student Procedures and Questions:**

1. Each member of your group should measure the length of the rectangle with the ruler or rulers you have been given to the nearest tenth of a centimeter. Record your group's measurements in yellow/shaded area of the following chart. M1 is Measurement 1, M2 is Measurement 2, etc. (Each person makes a single measurement with his or her ruler.)

| Ruler # | M1 | M2 | M3 | M4 (optional) |
|---|---|---|---|---|
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |
| 4 | | | | |
| 5 | | | | |
| 6 | | | | |
| 7 | | | | |
| 8 | | | | |

When all the class measurements have been recorded, the data should be typed into the Excel ® spreadsheet provided. You will need the resulting chart to answer the following questions.

2. All the rectangles are exactly the same size. Were all the measurements the same or at least close to the same number of centimeters for each ruler? (Were all the measurements made with ruler #1 the same or similar? With ruler #2?)

3. What is the purpose of making at least three measurments with each ruler?

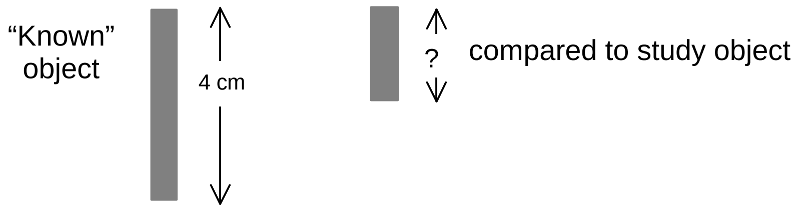
4. Were the measurements from ruler #1 the same as those for rulers #2 through #8?

5. Compare and contrast the different ruler measurements. Why might there be differences?

6. If multiple measurements were made with each ruler to minimize measurement error, what else might account for the differing results with each ruler?

**Measuring the Brightness Temperature of Jupiter – Student Activity Two**

Unlike rulers, radio calibration sources are not man-made to certain specifications. Scientists measure a study object like Jupiter by comparing it to an object that they already understand. For example, if a person has a stick that he knows is 4 centimeters long (calibration source), and he finds a stick that is exactly half the length of the 4 cm stick (study object), what length value does he assign to the new stick?




Scientists must compare objects they are studying, like Jupiter, to objects that are already well understood. Radio astronomers use galaxies, quasars, supernovas, planets, and nebulae that emit at radio wavelengths as radio calibration sources. These radio calibration sources have been observed over time, over a wide range of frequencies, using multiple instruments *with consistent results*. The more consistent the results, the more confidence scientists have in using a specific radio calibration source as a calibrator. As a result, there is a list of radio calibration sources with "known" brightness temperatures at various frequencies for each source. Scientists can use these for comparison to study sources. Our study object is Jupiter for this experiment. The radio calibration sources for the experiment include galaxies 3C123, 3C218; Virgo A (3C274); Signus A (3C405); the Orion Nebula (3C145); quasar 3C286; planetary nebula NGC 7027; and Venus. The study will also include observations of Saturn and Venus as study objects..

The rulers in Student Activity One are like the calibration sources. Ruler # 6, was not the standard size and measurements made with it made the study object (rectangle) seem to be smaller than it actually is. In the same manner, if a calibration source is actually stronger or weaker than we think it is, the calculated value for our study object may be too high or too low. By looking at the calculated brightness temperatures for Jupiter using different radio calibration sources, we can see if the data calculated from using the various radio calibration sources agree with one another, or if one or more sources are like ruler #6, indicating that the calibration sources may need further study.

Refer to "ratio_measurement_graph_092.xls" You will find three graphs to print showing the data that has been collected by middle and high school students in the GAVRT project. Each one of the three graphs is for a different frequency. Make sure you have a graph for each of the following frequencies: 8.480 MHz, 13. 8MHz, and 32 MHz. Use the graphs to answer the student questions.

The data is being collected in the 2000-2001 school year so the graphs will change over time, as new data become available. The results are not yet known. You may be witnessing a scientific "discovery." Have fun!

**Measuring the Brightness of Jupiter – Student Activity Two**

**Student Procedures and Questions:**

1. Look at the graph for Jupiter's brightness temperature in Kelvin at 8.480 MHz. What calibration sources were used?
2. How does the Jupiter brightness temperature data compare from calibration source to calibration source?
3. Do any of the results seem to disagree as different calibration sources were used?

**Repeat this process and record your answers in the following chart.** An example has been given for instructional purposes only, and it may not agree with your graphs.

| Frequency | List the Calibration Sources Used | Record Jupiter's Brightness Temperature in Kelvin for each calibration source | Do any of the calibration sources seem to disagree? | Recommendations for further study? |
|---|---|---|---|---|
| **8.480 MHz** | 3C_123 | 210.3 K | | |
| **13.8 MHz** | | | | |

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| | | | | |
|---|---|---|---|---|
| **32 MHz** | | | | |

**Set the three graphs side-by-side.**

4. Are there results from a particular radio calibration source or sources that do agree fairly well at one frequency, but not at another?

5. If the answer to number four is yes for any or all of the frequencies, what might be occurring?

**Mid-Continent Research for Education and Learning (McREL) Science Education Standards:**
http://www.mcrel.org/standards-benchmarks/

**1. Understands basic features of the Earth**
*Level III. Middle School/Junior High School*
- Knows that the Earth is the only body in our solar system that appears to support life

**3. Understands the essential ideas about the composition and structure of the universe and the Earth's place in it** (by comparison)
*Level II Upper Elementary*
- Knows that the Earth is one of several planets that orbit the sun and the moon orbits around the Earth
- Knows that astronomical objects in space are massive in size and are separated from one another by vast distances

*Level III Middle School/ Junior High School*
- Knows characteristics and movement patterns of the nine planets in our solar system (e.g. planets differ in size, composition, and surface features; planets move around the sun in elliptical orbits; some planets have moons, rings of particles, and other satellites orbiting them)

*Level IV High School*
- Knows ways in which technology has increased our understanding of the universe (e.g. visual, radio and x-ray telescopes collect information about the universe from electromagnetic waves; computers interpret vast amounts of data from space; space probes gather information from distant parts of the Solar System; accelerators allow us to simulate conditions in the stars and in the early history of the universe)

**14. Understands the nature of scientific knowledge**
*Level II: Upper Elementary*
- Knows that although the same scientific investigation may give slightly different results when it is carried out by different persons, or at different times or places, the general evidence collected from the investigation should be replicable by others

*Level III: Middle School/Junior High School*
- Knows that an experiment must be repeated many times and yield consistent results before the results are accepted as correct
- Knows that all scientific ideas are tentative and subject to change and improvement in principle, but for most core ideas in science, there is much experimental and observational confirmation
- Understands that questioning, response to criticism, and open communication are integral to the process of science (e.g., scientists often differ with one another about the interpretation of evidence or theory in areas where there is not a great deal of understanding; scientists acknowledge conflicting interpretations and work towards finding evidence that will resolve the disagreement)

*Level IV: High School*
- Knows ways in which science distinguishes itself from other ways of knowing and from other bodies of knowledge (e.g., use of empirical standards, logical arguments, skepticism)

- Knows that scientific explanations must meet certain criteria to be considered valid (e.g., they must be consistent with experimental and observational evidence about nature, make accurate predictions about systems being studied, be logical, respect the rules of evidence, be open to criticism, report methods and procedures, make a commitment to making knowledge public)
- Understands how scientific knowledge changes and accumulates over time (e.g., all scientific knowledge is subject to change as new evidence becomes available; some scientific ideas are incomplete and opportunity exists in these areas for new advances; theories are continually tested, revised, and occasionally discarded)
- Knows that from time to time, major shifts occur in the scientific view of how the world works, but usually the changes that take place in the body of scientific knowledge are small modifications of prior knowledge

**15. Understands the nature of scientific inquiry**

*Level II: Upper Elementary*

- Knows that scientific investigations involve asking and answering a question and comparing the answer to what scientists already know about the world
- Knows that scientists use different kinds of investigations (e.g., naturalistic observation of things or events, data collection, controlled experiments), depending on the questions they are trying to answer
- Plans and conducts simple investigations (e.g., makes systematic observations, conducts simple experiments to answer questions)
- Uses simple equipment and tools to gather scientific data and extend the senses (e.g., rulers, thermometers, magnifiers, microscopes, calculators)
- Knows that good scientific explanations are based on evidence (observations) and scientific knowledge
- Knows that scientists make the results of their investigations public; they describe the investigations in ways that enable others to repeat the investigations
- Knows that scientists review and ask questions about the results of other scientists' work
- Knows that different people may interpret the same set of observations differently

*Level III: Middle School/Junior High School*

- Knows that there is no fixed procedure called "the scientific method," but that investigations involve systematic observations, carefully collected, relevant evidence, logical reasoning, and some imagination in developing hypotheses and explanations
- Designs and conducts a scientific investigation (e.g., formulates questions, designs and executes investigations, interprets data, synthesizes evidence into explanations, proposes alternative explanations for observations, critiques explanations and procedures)
- Knows that observations can be affected by bias (e.g., strong beliefs about what should happen in particular circumstances can prevent the detection of other results)
- Uses appropriate tools (including computer hardware and software) and techniques to gather, analyze, and interpret scientific data
- Establishes relationships based on evidence and logical argument (e.g., provides causes for effects)

- Understands the nature of scientific explanations (e.g., emphasis on evidence; use of logically consistent arguments; use of scientific principles, models, and theories; acceptance or displacement based on new scientific evidence)
- Knows that scientific inquiry includes evaluating results of scientific investigations, experiments, observations, theoretical and mathematical models, and explanations proposed by other scientists (e.g., reviewing experimental procedures, examining evidence, identifying faulty reasoning, identifying statements that go beyond the evidence, suggesting alternative explanations)
- Knows possible outcomes of scientific investigations (e.g., some may result in new ideas and phenomena for study; some may generate new methods or procedures for an investigation; some may result in the development of new technologies to improve the collection of data; some may lead to new investigations)

*Level IV: High School*

- Understands the use of hypotheses in science (e.g., selecting and narrowing the focus of data, determining additional data to be gathered; guiding the interpretation of data)
- Designs and conducts scientific investigations by formulating testable hypotheses, identifying and clarifying the method, controls, and variables; organizing and displaying data; revising methods and explanations; presenting the results; and receiving critical response from others
- Knows that a wide range of natural occurrences may be observed to discern patterns when conditions of an investigation cannot be controlled
- Uses technology (e.g., hand tools, measuring instruments, calculators, computers) and mathematics (e.g., measurement, formulas, charts, graphs) to perform accurate scientific investigations and communications
- Knows that conceptual principles and knowledge guide scientific inquiries; historical and current scientific knowledge influence the design and interpretation of investigations and the evaluation of proposed explanations made by other scientists
- Knows that scientists conduct investigations for a variety of reasons (e.g., to discover new aspects of the natural world, to explain recently observed phenomena, to test the conclusions of prior investigations, to test the predictions of current theories)
- Knows that investigations and public communication among scientists must meet certain criteria in order to result in new knowledge and methods (e.g., arguments must be logical and demonstrate connections between natural phenomena, investigations, and the historical body of scientific knowledge; the methods and procedures used to obtain evidence must be clearly reported to enhance opportunities for further investigation)

### 16. Understands the nature of scientific enterprise

*Level II: Upper Elementary*

- Knows that people of all ages, backgrounds, and groups have made contributions to science and technology throughout history
- Knows that although people using scientific inquiry have learned much about the objects, events, and phenomena in nature, science is an ongoing process and will never be finished
- Knows that scientists and engineers often work in teams to accomplish a task

*Level III: Middle School/Junior High School*

- Knows that people of all backgrounds and with diverse interests, talents, qualities, and motivations engage in fields of science and engineering; some of these people work in teams and others work alone, but all communicate extensively with others
- Knows that the work of science requires a variety of human abilities, qualities, and habits of mind (e.g., reasoning, insight, energy, skill, creativity, intellectual honesty, tolerance of ambiguity, skepticism, openness to new ideas)
- Knows various settings in which scientists and engineers may work (e.g., colleges and universities, businesses and industries, research institutes, government agencies)
- Understands ethics associated with scientific study (e.g., potential subjects must be fully informed of the risks and benefits associated with the research and their right to refuse to participate; potential subjects must be fully informed of possible risks to community and property)
- Knows that throughout history, many scientific innovators have had difficulty breaking through accepted ideas of their time to reach conclusions that are now considered to be common knowledge
- Knows ways in which science and society influence one another (e.g., scientific knowledge and the procedures used by scientists influence the way many individuals in society think about themselves, others, and the environment; societal challenges often inspire questions for scientific research; social priorities often influence research priorities through the availability of funding for research)

*Level IV: High School*

- Knows that throughout history, diverse cultures have developed scientific ideas and solved human problems through technology
- Understands that individuals and teams contribute to science and engineering at different levels of complexity (e.g., an individual may conduct basic field studies; hundreds of people may work together on a major scientific question or technological problem)
- Understands the ethical traditions associated with the scientific enterprise (e.g., commitment to peer review, truthful reporting about the methods and outcomes of investigations, publication of the results of work) and that scientists who violate these traditions are censored by their peers
- Knows that science and technology are essential social enterprises, but alone they can only indicate what can happen, not what should happen
- Understands that science involves different types of work in many different disciplines (e.g., scientists in different disciplines ask different questions, use different methods of investigation, and accept different types of evidence to support their explanations; many scientific investigations require the contributions of individuals from different disciplines; new disciplines of science, such as geophysics and biochemistry, often emerge at the interface of older disciplines)
- Knows that creativity, imagination, and a good knowledge base are all required in the work of science and engineering